U.S. ARMY MATERIALS RESEARCH AGENCY
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METALLURGICAL ADVISORY COMMITTEE ON TITANIUM

Summary of Round Table Meeting

on

Surface Treatment of Titanium

Watertown Arsenal

Watertown 72, Massachusetts

20 May 1952

Attendance at Round Table Meeting on Surface Treatment

of Titanium, 20 May 1952

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Attendance at Round Table Meeting on Surface Treatment

of Titanium, 20 May 1952

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AGENDA
ROUND TABLE MEETING
on
SURFACE TREATMENT OF TITANIUM
20 May 1952 - 10:00 AM
Conference Room, Bldg 74
Watertown Arsenal Laboratory
Watertown 72, Massachusetts

Opening Remarks: Colonel B. S. Mesick, Commanding Officer, Watertown Arsenal

Introduction: Mr. M. M. Jacobson
Technical Chairman

1. Carburizing and Induction Hardening
   - Battelle Memorial Institute

2. Nitriding
   (A) - Sam Tour and Company, Inc.,
   (B) - Watertown Arsenal

3. Surface Hardening with Metalloid Elements
   - Armour Research Foundation

4. Siliconizing
   - Fansteel Metallurgical Corporation

5. Vapordeposited Coatings
   - Sam Tour and Company, Inc.

6. Chemical Surface Treatment
   - Battelle Memorial Institute

7. Electrodeposited Coatings
   (A) - Armour Research Foundation
   (B) - Watertown Arsenal

8. Wear and Friction Studies
   (A) - Massachusetts Institute of Technology
   (B) - Carnegie Institute of Technology

-UNCLASSIFIED-

SUMMARY OF ROUND TABLE MEETING ON SURFACE TREATMENT OF TITANIUM

Watertown Arsenal
20 May 1952

Colonel A. Schomburg, Director of Research, Development and Engineering, Watertown Arsenal, introduced Colonel B. S. Mesick, Commanding Officer of Watertown Arsenal and Titanium Coordinator for the Department of the Army who opened the meeting. Colonel Mesick described the scope of the overall research and development program on titanium and indicated the growth and present status of titanium production.

Mr. M. M. Jacobson of Watertown Arsenal Laboratory, Technical Chairman, outlined the agenda of the meeting. Mr. Jacobson stated that among the objectives of studies of surface treatment of titanium may be included: the development of hard, wear-resistant surfaces; the overcoming of undesirable galling and seizing tendencies; the facilitating of joining operations; the development of oxidation-resistant surfaces; and, the development of better lubricant-retaining surfaces.

1. Carburizing and Induction Hardening.

Mr. Paul D. Frost reviewed the Ordnance Corps contract studies at Battelle Memorial Institute on surface hardening of titanium by carburizing and induction heating techniques.

It was indicated that the mechanism by which carburization hardens titanium differs from that of steel. Carbon has only limited solubility in the high-temperature, beta phase of titanium. Therefore, carburized titanium, unlike carburized steel, is not amenable to hardening by solution treating and quenching. Carburized titanium is hardened by the formation of a layer of massive TiC on the surface.

The following three carburizing methods are being investigated:

a. Pack carburizing in a commercial carburizing compound, or in lampblack with an argon atmosphere.

b. Gas carburizing in mixtures of propane and argon.

c. Liquid carburizing in baths consisting largely of sodium cyanide.

The best pack-carburizing results were obtained on specimens treated in a commercial compound for 8 hours at 1750°F. A case about 0.004 inch deep, having a hardness of 950 Knoop, was formed. X-ray diffraction results show that cases formed under these conditions are not massive TiC but alpha titanium containing dissolved carbon, oxygen, and possibly nitrogen.

Specimens pack-carburized in lampblack, with oxygen and nitrogen excluded, or gas-carburized in propane-argon mixtures, formed cases of massive TiC. These were hard (1000-1270 Knoop) but less adherent and more brittle than the cases produced by the commercial pack-carburizing compound.

Preliminary experiments on liquid carburizing show that the surface hardness of titanium is increased by holding in NaCN-base baths for 1-1/2 to 5 hours at 1550°F. Nature of the cases has not been established.

Results of qualitative abrasion tests have indicated that abrasion resistance of carburized titanium is considerably better than that of untreated titanium. Quantitative wear tests are being initiated.

Since unalloyed titanium is not hardened appreciably by heat treatment, induction hardening tests will be restricted to alloys which contain beta-stabilizing elements such as iron, manganese, chromium, etc. Alloys of this type are susceptible to coherency hardening after cooling rapidly from the beta field. Although initial experiments were made using a frequency of 9600 cycles, current effort is being aimed at improving the control over the geometry of the heated zone through use of higher frequencies (200-500 kc) and alteration of coil design.

2. <u>Nitriding.</u>

A. The status of Ordnance Corps studies on nitriding and carbonitriding of titanium at Sam Tour and Co., Inc., were reported by Mr. Edmund J. Silk. Mr. Silk described the apparatus which was designed and built for nitriding of titanium. The apparatus consisted of a resistance-wound furnace with a convenient observation port. The ends of the quartz tube were cooled with water running through copper coils. The temperature within the furnace was controlled by a pyrometer. Ammonia or nitrogen was fed into the furnace through a dehydrator and through a flowmeter. The dissociation apparatus was hooked into the line after the furnace and remained in the line except when actual dissociation measurements were taken.

Standard runs of 3, 16, and 64 hours were made on unalloyed RC-55 and various alloy materials. Temperatures of from

900-1700°F, at 100°F intervals were used with commercial ammonia and 1300°F, 1500°F, and 1800°F with commercial nitrogen.

Specimens were placed in an alundum boat in the cold end of the furnace. The furnace was flushed with the gas to be used, then heated up and allowed to stabilize, after which the specimens were moved to the hot zone. After the treating cycle the specimens were moved back to the cool end of the furnace and the furnace allowed to cool with the gas still flowing. The amount of ammonia dissociation did not appear to be critical.

Several slides were shown containing data on weight change, and hardness gradient as well as illustrating the microstructure of nitrided cases developed. The data indicated that RC-55 titanium has a minimum treating temperature of 1400°F, with best results being obtained at 1600°F for a treating time of 16 hours. Sixty-four hour treatments caused a loss in hardness in RC-55. For one ferrochromium titanium alloy the best treatment was 1600°F for 16 hours; whereas an alloy of slightly lower ferrochromium content showed maximum hardness after a 64 hour treatment at 1600°F. (This hardness was Vickers 1098).

Treatments in nitrogen gave somewhat different results. RC-55 grade showed greatest hardening effect when treated at 1800°F for 3 hours; one of the ferrochromium titanium materials showed greatest hardening at 1800°F for 16 hours.

Case depths, although relatively shallow, were highly adherent and apparently continuous, with no spalling or cracking during cutting and polishing. Hardness surveys showed considerable hardening extending below the case. Indications, at present, are that the treatments embrittle the core.

It was indicated that alloying elements apparently have a definite effect upon hardness, case thickness, and treating temperatures.

B. Mr. William H. Duffy reported on experiments at Watertown Arsenal Laboratory dealing with air-oxidation of titanium at temperatures of 1200-1700°F and ammonia nitriding in the range of 1300-1800°F.

The following materials were used in oxidation tests conducted at an air flow of 500 ml. per minute: commercial unalloyed titanium, titanium containing 0.78% carbon, 4% ferrochromium alloy, 7% ferrochromium alloy, 4% aluminum-4% manganese alloy and 7% manganese alloy. The oxidation reaction followed the parabolic law prediction in all cases, with the 4% aluminum-4% manganese titanium alloy showing the lowest oxidation rate.

Rates of reaction followed an exponential function of the temperature; in the temperature range tested straight line plots were obtained in accordance with the Arrhenius reaction rate equation. In tests conducted up to 16 hours duration appreciable hard layers developed only at 1700°F, although at this temperature the main scale spalled badly. Underneath the spalled scale, hard layers, .0025 inch were noted which possessed a hardness of approximately 600-800 Knoop.

During ammonia nitriding runs gas flow was kept constant at 900 ml./min. Ammonia dissociation ranged from 75% at 1300°F to practically 100% at 1800°F. Most runs were of 48 hour duration although some were made for 24 and 72 hours. Knoop hardness measurements of nitrided cases were made in general with a 25 gram load.

All specimens were smooth on removal from the furnace and had a golden yellow color which deepened to bronze at higher temperatures. A light etching case was observed in all instances; the case varied in depth from 0.0002 inch on 7% ferrochromium alloy nitrided at 1300°F for 48 hours to .0030 inch on unalloyed titanium and 4% aluminum-4% manganese when nitrided at 1800°F for 48 hours. The hard cases were very adherent. The highest hardness value (1908 Knoop) was noted with 4% aluminum-4% manganese alloy nitrided for 24 hours at 1600°F.

In nitriding tests of unalloyed titanium specimens that were previously subjected to anodizing treatment (e. g. in 0.25% fluoboric acid solution), it has been possible to develop considerably thicker cases than those obtained on un-anodized specimens nitrided under the same conditions. The thicker case is believed to comprise a solid solution of titanium nitride and titanium oxide.

In order to determine the affect of nitriding on the physical properties of titanium, V-notch impact specimens of unalloyed titanium and ferrochromium titanium alloy were subjected to commercial nitriding conditions at 965°F for 48 hours. (No measurable hard case was developed at this low temperature). Degassing was not employed after processing. The decrease in impact energy at room temperature as a result of nitriding is shown in the tabulation below:

	Impact Energy ft/lbs	
	Before Nitriding	After Nitriding
Unalloyed titanium	20.8	12.5
4% ferrochrome alloy	11.8	8.3
7% ferrochrome alloy	18.1	3.1

Mr. Sam Tour of Sam Tour and Co., Inc., in discussion pointed out the need for reporting hardnesses of cases in a consistent manner. He suggested that Vickers hardness at 100 grams load be reported in the future, together with Knoop measurements, if desired.

3. Surface Hardening with Metalloid Elements.

Mr. Richard W. Hanzel of Armour Research Foundation presented a summary of surface hardening studies, under Ordnance Corps sponsorship, involving the metalloid elements oxygen, nitrogen, carbon, boron, and hydrogen. Treatment to date has consisted primarily of heating commercial unalloyed titanium in air, solid carbon, propane, nitrogen, and molten borax.

Titanium-base binary alloys of 1, 3, and 5 atomic percentages of V, Zr, Cr, C, B, and Al have been prepared. Treatment of these alloys, as well as several commercial alloys, has been carried out only in nitrogen.

The heating of commercially-pure titanium in air and commercial carburizing compound is believed to result essentially in oxygen absorption. Considerable hardening was achieved in both treatments, but it was accompanied by extensive scaling and embrittlement. Specimens treated in carburizing compound at temperatures between 1600 F and 2000 F for both 6 and 16 hours crumbled when subjected to the slightest pressures. However, a few preliminary runs in dry air (dew point -65 C) seemed to reduce scaling considerably.

Commercially pure titanium specimens packed in degassed powdered graphite under vacuum and treated at 1000 F to 2000 F showed moderate hardening, but surface conditions and brittleness above 1400 F prevented satisfactory evaluation.

Specimens were also treated in propane gas, but only at 2000 F, since at lower temperatures, decomposition products were considered undesirable. At 2000 F, the breakdown of propane is essentially into carbon and hydrogen. At 2000 F, considerable "sooting" was encountered which blocked gas flow and consequently limited the time to relatively short periods. A heavy, loosely adhering, carbon layer resulted. Further investigation is planned using hydrogen, helium, and nitrogen as individual diluents for the propane. It is believed that this will eliminate the sooting and formation of undesirable surface layers.

The electrolytic treatment of titanium in molten borax is still in its early stages. However, preliminary results seem to indicate that the process may have promise. Several specimens exhibited surface hardness between 1300 and 1500 Vickers.

The treatment of commercially-pure titanium and its alloys in a purified tank nitrogen atmosphere seems to be the most promising at this time. Hardening is evident at temperatures of 1400 F and above. The hardness and depth of penetration increases with the time and temperature of treatment. A distinct, light etching band on the outer edges of the specimen is evident after treatment above 1400 F. This band alsoiincreases in thickness with time and temperature. The band appears to be adherent and dense. A slight brittleness is evident on the surface at 1800 F. This brittleness increases with temperature.

Specimens treated at 1600 F for 16 hours appear to have promising surface characteristics. The surface hardness of the material varies between 750 and 850 Vickers. An intensive study of the effect of time and surface condition in the 1500-1700 F temperature range is being initiated.

A series of titanium-base binary alloys is under consideration. Some of these alloys will stabilize the beta phase at lower temperatures. This will make surface impregnation with the metalloids possible at these lower temperatures where less grain growth is encountered. The effect of this grain growth on the mechanical properties is not known, as yet; however, it is reasonable to expect it to reduce the ductility of the core. A few of the alloys may induce a dispersion hardening.

Specimens are being prepared for evaluation of qualitative friction characteristics of the surfaces produced in the afore-mentioned studies.

4. Siliconizing.

A discussion of the research under Ordnance Corps contract at Fansteel Metallurgical Corporation on development of oxidation resistant coatings on titanium by siliconizing was presented by Dr. L. F. Yntema.

The first part of this study had as its objective the determination of oxidation rates of titanium-silicon composites having various ratios of components. Mixtures of the two powders were heated in hydrogen at 1350 C. The products, hard brittle masses with metallic luster, were crushed and ball milled. The

powders were than pressed cold into pellets 1" in diameter and 0.1" thick and subsequently sintered in hydrogen at 1450°C for 30-60 minutes.

Compacts with nominal compositions TiSi, $TiSi_2$, Ti_2Si_3 and Ti_2Si were investigated. The last, Ti_2Si, could not be sintered below 1500°C, and it was not investigated further.

In heating tests in stagnant air at 1000°C, the composition $TiSi_2$ showed the least percentage weight change and the least percentage volume change. Compacts of the compositions TiSi and Ti_2Si_3 developed glossy layers that spalled off, while the $TiSi_2$ compact showed no significant change except a slight loss in color.

X-ray examination of the compacts gave the following information:

Nominal Powder Composition	Phases after Firing at 975 C.	Phases after Firing at 1200 C
$TiSi_2$ (46% titanium)	$TiSi_2$, Ti, Si	$TiSi_2$
Ti_2Si_3 (54% titanium)	$TiSi_2$, eta phase	$TiSi_2$, eta phase
TiSi (63% titanium)	$TiSi_2$, eta phase	$TiSi_2$, eta phase
Ti_2Si (77% titanium)	Ti_5Si_3	Ti_5Si_3

The eta phase was not identified; it may be TiSi. These data indicate the probably usefulness of a coating of the composition $TiSi_2$.

The formation of a titanium silicide coating can be accomplished by heating or sintering silicon powder spread over a titanium surface.

A suspension of silicon powder (4.5 microns average particle size) in a solution of Glyptal in acetone and diacetone alcohol was painted on the test pieces. The reaction between the titanium base was carried out by heating in a protective atmosphere of purified hydrogen or helium. The treatment consisted in heating at 350 C to drive off the binder and traces of solvent, and then at 1300 C. The coatings were 0.002" thick, smooth, and dark gray in color.

Compositions of the coatings have not been thoroughly investigated. Micro-examination of the "as-coated" structure indicates the presence of three phases of which the outer has been identified in the outer layer.

The best oxidation resistance reported was 260 hours at 1000 C. Failure seems to be caused by "pin holes" in the coating and loss of silicon by diffusion into the body of the titanium.

5. Vapor Deposited Coatings.

Mr. Sam Tour of Sam Tour and Company, Inc., reported on the Ordnance Corps work his company is doing on development of techniques for applying adherent vapor deposited metallic coatings on titanium.

A literature survey gave very little information on titanium as a substrate for vapor coatings. Literature on the vapor deposition of various metals on other metals indicated, however, that the metal carbonyls were quite promising for this type of work.

Molybdenum carbonyl was chosen for the original tests for the following reasons:

a. The previous success of the metal carbonyls.

b. The availability of molybdenum carbonyl.

c. The low plating and decomposition temperatures of molybdenum carbonyl.

d. The desirability of vacuum processing.

The apparatus consisted essentially of a supply of carbonyl, a temperature-controlled oil bath to keep the carbonyl at the proper temperature, a hydrogen supply, a control for the hydrogen supply, a plating chamber which was essentially a quartz tube, a source of high frequency induction heat, a suitable pyrometer controller, a vacuum pump and a vacuum gauge.

Experimental work was carried out with small samples, usually 1/2" cubes, of RC-130A titanium alloy. Samples were machined on all surfaces and were carefully cleaned, chemically, prior to actual test.

Resistance heating of the quartz plating chamber proved completely unsatisfactory, resulting in coating of the tube itself, formation of heavy soot deposits and little or no plating on the titanium. To overcome this, induction coils were substituted for the resistance furnace. This procedure gave a hot sample with a relatively cool tube and was employed on all subsequent runs.

Uniform and adherent deposits were obtained in 3 to 6 hours in the temperature range of 930-1130°F., with carbonyl pressures of about 0.1 min. and hydrogen pressures of about 0.2 min. of mercury.

Slides were shown illustrating the RC-130A titanium material as received and after molybdenum plating.

The studies to date with the carbonyls have shown that it is possible to plate out an adherent and apparently continuous molybdenum film on titanium alloys. Plate characteristics vary with the processing conditions. No attempt has been made, as yet, to determine the structures and composition of the plate as received.

6. Chemical Surface Treatment.

The Ordnance Corps contract studies on chemical surface treatment of titanium was summarized by Dr. Paul D. Miller.

A broad survey was made of the chemical and electrochemical action of various solutions on titanium. Principal emphasis was placed on the production of oxide coatings; but some attempt was also made to produce phosphate and sulfide films. Over 150 different baths have been tested, several of which were found to produce coatings with outstanding properties.

In general, the coatings obtained by chemical action, when titanium was immersed in the appropriate solutions, were limited to thin colored films. However, the following composition furnished immersion coatings of measurable thickness and potential value:

KF	42 grams per liter
$Na_3PO_4 \cdot 12H_2O$	80 grams per liter

Considerable attention has been given to electrochemical methods for treating titanium anodically because thicker and more durable coatings appeared to be produced in this manner. Both acid and alkaline solutions can be used, as is shown by several bath compositions indicated below:

	BATH COMPOSITION	OPERATING CONDITIONS
(a)	5% $NaOH$	95°C; 30 volts; 7-70 asf; 30 min.
(b)	5% Na_2O_2 1% $NaH_2PO_4 \cdot H_2O$	45°C; 40 volts; 50 asf; 5 minutes
(c)	5% $NaAlO_2$ 1% $NaH_2PO_4 \cdot H_2O$	90°C; 30-105 volts; 50 asf; 10 min.
(d)	0.25% HBF_4	25°C; 110 volts; 10 asf; 30 min.
(e)	5% $HCOOH$	35°C; 100 volts; 10 asf; 30 min.

As would be expected many different types of coatings were produced. Deposits varied from white to gray in color, and from coarse, non-adherent crystalline to fine-grained adherent layers.

Adherence and thickness were studied by examining under a low power microscope and scratching with a steel probe.

Indication of continuity and durability of the coating was obtained by measuring the d.c. breakdown voltage.

After it was shown that a coating warranted further testing, methods for evaluating wear and anti-seizing properties were investigated.

Favorable results were obtained on the Taber Abraser. More severe tests were then made using methods which involved pressures nearer those required in practical drawing and forming operations. One apparatus, using loads of 140,000 psi showed that anodized surfaces withstood galling for up to 250 strokes, while bare titanium galled on the first stroke. In a similar manner, wire-drawing tests indicated that anodized wire could be given up to 7 consecutive reductions, while bare were seized at the first reduction. In both of these tests, it was necessary to employ oil or other lubricant along with the anodic coating.

Improved paint adhesion on anodically treated titanium surfaces was also reported.

7. Electroplating on Titanium.

A. Dr. H. T. Francis and Dr. M. Feinleib of Armour Research Foundation described Ordnance Corps sponsored research pertaining to electroplating on titanium.

The difficulty in plating on titanium lies in the fact that titanium is a very active metal, which is normally coated with a tightly adherent scale. Most media powerful enought to dissolve the oxide will react violently with the metal once the oxide has been removed.

The first methods of attack followed the pattern used for preparing steels or magnesium for plating, involving ordinary pickles, nickel pickles, and immersion coatings. None of these methods yielded adherent plates and it was apparent that more drastic means were necessary.

A zinc strike in an essentially non-aqueous bath containing HF was the first successful method to produce adherent electrodeposits on titanium. Ethylene glycol was the best organic solvent found. A typical bath forulation comprised 10% HF, 3% H_2O 0.5% $ZnCl_2$, and 86.5% ethylene glycol.

Good adherence was obtained with copper electrodeposits (over a zinc strike) in thicknesses of copper up to 0.0005 inch. The adherence of heavier deposits has not come up to that of the usual electroplates. Adherence is evaluated by scraping with a knife, bending and flexing of flat specimens and breaking soldered joints made to the copper plate.

The mechanism of the zinc strike has not been clearly understood. Underneath an adherent zinc coating, an adherent, composite black film is formed, and the presence of this black film seems to be necessary for good bonding.

Current density and time of strike must be controlled within limits to obtain adherent deposits. "commercially pure titanium" from different sources behaves differently in the strike.

Some degree of adherence was obtained on titanium treated in a zinc <u>immersion-plating</u> solution containing fluoride. Here again, adherence seems to depend upon the formation of a black film under the zinc immersion plate.

Initial experiments on anodic treatments in an ethylene glycol-HF bath have yielded excellent adherence which may have been attributable to a roughening of the metal surface. Under conditions conducive to electropolishing, adherence was very poor.

Mr. W. C. Troy of Armour Research Foundation during discussion suggested the possibility of electroplating titanium with copper as a means of preventing access of oxygen and hydrogen but not nitrogen during nitriding treatments.

B. Mr. C. Levy discussed the efforts being made at Watertown Arsenal Laboratory to electrodeposit chromium directly on titanium. On sheet or forged titanium material, fair to good adherent chromium deposits have been achieved only in the case of mechanically roughened surfaces. None of the usual methods of preparing steel, stainless steel or other passive metals offered promise.

Non-adherent deposits also resulted from pre-treatments involving acid pickling, HF, or mixtures of HF and NHO_3, containing

surface active agents. A treatment for activating the surface of berylium prior to plating, which involved a phosphoric acid etch, proved unsatisfactory for titanium. Use of superimposed AC current on DC current; and attempts to plate on anodized titanium surfaces also proved negative. Non-adherent deposits were also obtained from chromium baths containing fluosilicic acid operated at a range of temperatures and current densities. However, when titanium is mechanically roughened to produce a surface roughness of approximately 75 micro-inches, (achieved by sand-blasting with 80 grit silica sand at 90 psi), uniform good appearing chromium deposits are obtainable from conventional chromium baths. In thicknesses up to .001" such deposits show satisfactory adherence in tension under bend test conditions.

Chromium has been readily applied to a crystalline fractured surface of an iron-chromium titanium alloy possessing exceptionally large grain size. Micro-examination of the chromium coating at smooth crystal faces of this titanium surface revealed excellent bonding. Crystal orientation and state of stress at titanium surfaces are undoubtedly important factors governing adhesion of electrodeposits to titanium and warrant further study.

8. Wear and Friction Studies.

Dr. E. Rabinowicz reported on wear and friction studies on titanium being sponsored by Navy Bureau of Aeronautics at Massachusetts Institute of Technology.

Dr. Rabinowicz discussed consideration of low shear strength versus hard layers as factors influencing friction and also reviewed the classical definitions of friction involving the following relationshops:

$\mu = F/L$; $F = A.S$; $L = A.P$

where μ=coefficient of friction
F=force necessary to overcome friction
L=load pressing the surfaces together
A=area of real contact
S=shear strength of softer material
P=Yield strength of softer material.

The essential components of the Massachusetts Institute of Technology test apparatus consisted of a flat rotating or reciprocating specimen acting against a ball or hemisphere bearing specimen. It was pointed out in accordance with the relationships indicated above that the area of real contact, for any given load was always such that the unit pressure remained constant. That is, provided the elastic limit of the softer material was not exceeded, the unit pressure exerted was equivalent to the yeild strength of the softer material.

With no lubricant, a coefficient of friction of 0.45 was reported for clean titanium against titanium, under load conditions of 50-1000 grams. Lubricants were ineffective in lowering friction. However, titanium in combination with a dissimilar metal resulted in very high friction values.

A coefficient of friction of 0.08 was observed on titanium surfaces which had been nitrided. It was indicated that surface treatment of titanium affords reduced values of friction provided the coating or skin does not become ruptured.

Further work is planned involving the effect of lubricants. Radio-tracer techniques will also be employed in future experiments.

B. Dr. W. C. Leone reviewed the Ordnance Corps studies at Carnegie Institute of Technology on galling and seizing characteristics of titanium. The work involves investigation of the load and speed conditions for galling and seizing, and friction studies of titanium materials with and without lubrication.

A literature survey revealed that important factors in friction and seizing of metals rubbed together included: real area of contact, normal load, speed, roughness, adhesion, absorbed films, and temperature.

In this study, it was planned to make initial observations of galling of dry titanium material under conditions of varying load and speed. A measure of coefficient of friction was also desired, and since available commercial testing machines were not adequate, effort was directed toward adapting an existing machine for the measurement of friction forces between specimens at various pressures and speeds. Details of the design of the test apparatus were described.

Initial crude tests were made with a rig on a lathe to determine loads and speeds at which galling occurred so as to furnish a basis for determining the ranges over which more extensive measurements must be made. The test set-up provided a means for rubbing a titanium rod on the surface of a rotating titanium plate.

The first noticeable change was the appearance of a shiny path along the rubbing circle on the plate. At first the path had no depth; but as rubbing continued, especially with increasing load, the path widened and deepened into a groove. Finally, the groove became badly torn and showed traces of powdered metal. Most of these metal powders were traceable to the plate material. Sometimes particles of rod material adhered loosely to the plate, depending upon the type of rod material employed.

The initial tests also revealed that roughness of either rubbing surface had a pronounced effect on galling. If galling started on one surface, the mating surface tended to gall within a short time.

Extensive quantitative friction measurements are planned, using various commercial titanium materials, both with and without special surface treatments.

M. M. Jacobson

MURRAY M. JACOBSON
Technical Chairman